EC/JRC Nuclear Science Training Course with Nucleonica

ITRAC-3: 3rd Training Course on Illicit Trafficking and Radiological Consequences with NUCLEONICA

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Radiological Quantities and Units

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Learning Objectives

• To become familiar with basic radiological units such as becquerel (Bq), curie (Ci), sievert (Sv), etc.

• To become familiar with basic radiological quantities such as activity, specific activity, dose rate, etc.

• To understand the relationships between the basic units

• To get to know how to use the Mass Activity Calculator module in Nucleonica to convert between different units. This requires familiarity with the Glossary, Help, Calculator

• To strengthen the above understanding through a series of problems and exercises.

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Radiological Quantities and Units

1. **Basic Quantities and Relations**
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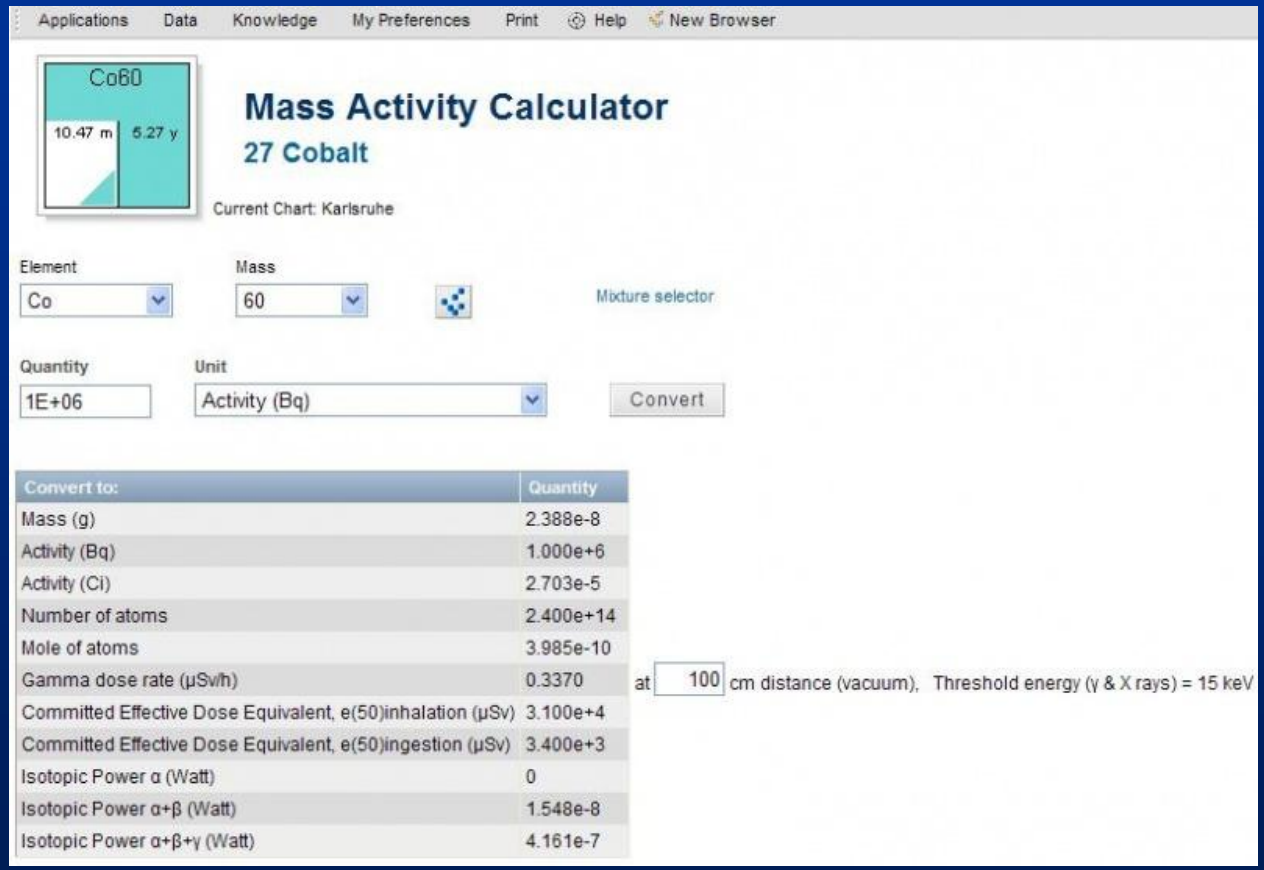
The mass activity calculator is a popular tool for conversion between different physical quantities (e.g. mass, activity, number of atoms, etc.). A particularly useful feature is that in addition to single nuclides, the mass activity calculator can also be applied to nuclide mixtures. These nuclide mixtures can be created with the Nuclide Mixtures module. The Convert to box shows the full list of quantities. In addition to the standard list (mass, activities, etc.), conversions can also be made using:

- external and internal dosimetry quantities such as the gamma dose rate (where the distance is required)
- the committed effective doses for inhalation and ingestion.
- the amount of heat generated – isotopic power – through radioactive decay for α, α+β, α+β+γ.



In the above example, the nuclide Co-60 is selected. A different nuclide can be selected from the element and mass drop-down menus. The default source strength is 1 MBq. In the unit drop-down menu, the source strength is shown in becquerel (Bq), curie (Ci), number of atoms, etc. The user can also select a previously defined nuclide mixture (by clicking on the Mixture selector). Further information is given in the Nucleonica wiki.

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Nucleonica's Mass Activity Calculator [edit]

The mass activity calculator is a popular tool for conversion between different physical quantities (e.g. mass, activity, number of atoms, etc.). A particularly useful feature is that in addition to single nuclide, the mass activity calculator can also be applied to nuclide mixtures. These nuclide mixtures can be created with the Nuclide Mixtures module. The Convert to box shows the full list of quantities. In addition to the standard list (mass,activities, etc.), conversions can also be made using:

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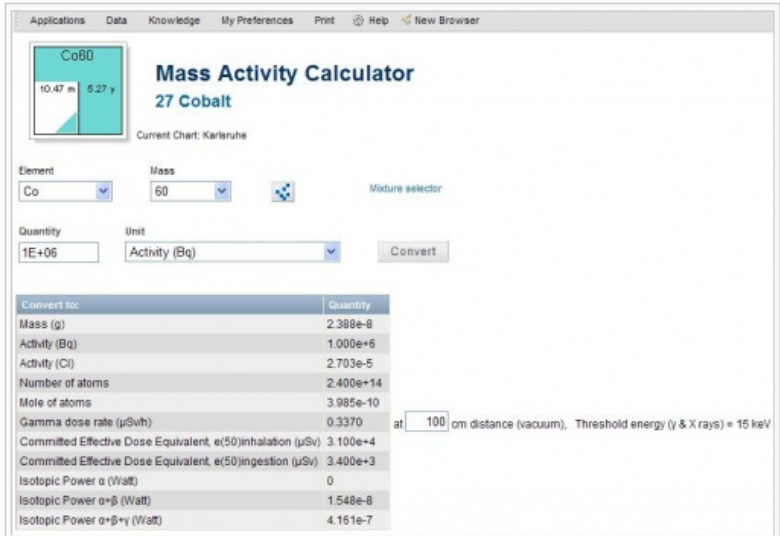


Mass Activity Calculator

In the above example, the nuclide Co-60 is selected. A different nuclide can be selected from the element and mass drop-down menus. The default source strength is 1 MBq. In the unit drop-down menu, the source strength is shown in becquerel (Bq), curie (Ci), number of atoms, etc. The user can also select a previously defined nuclide mixture (by clicking on the Mixture selector). Further information is given in the

1. Basic Quantities and Relations

In this section, the basic relationships between number of atoms, mass, and activity, are developed. From these basic quantities, additional quantities such as the gamma dose rate, the effective doses for inhalation and ingestion and the isotopic powers can be obtained.

For an amount of material with mass in grams given by $Mass(g)$, the number of atoms N is given by

$$\frac{N}{N_A} = \frac{Mass(g)}{M} \quad \text{or} \quad N = Mass(g) \cdot \frac{N_A}{M}$$

Where N_A is Avogadro's number or Avogadro's constant ($N_A = 6.002214179\text{x}10^{23}$), and M is the atomic mass of the nuclide. This basic relationship follows from the fact that 1 mole of any material contains Avogadro's number of atom.

The conversion of number of atoms to the number of moles is given by

$$\text{Number of moles} = \frac{N}{N_A}$$

The conversion from number of atoms to activity, and vice versa, is obtained using

$$Activity(Bq) = k \cdot N = \ln 2 \cdot N / \tau$$

$$Activity(Ci) = Activity(Bq) / 3.7 \cdot 10^{10}$$

Where k, and τ are the decay constant and half-life respectively of the nuclide. Combining the above relations, it follows that the relation between activity and mass is given by

$$Activity(Bq) = (\ln 2 / \tau) \cdot Mass(g) \cdot N_A / M$$

2. Derived Quantities

From the activity A, additional important quantities such as the gamma dose rate, the committed effective doses and the isotopic powers can be derived. The relations used in the Mass Activity Calculator are given below. For more details on the meaning and derivation of these quantities, the reader should follow the links.

The gamma dose rate in tissue, dH/dt, (follow the link for the derivation) is given by

$$\frac{dH}{dt} = A/(4\pi R^2) \cdot \sum_i (E_i \cdot P_i \cdot (\mu_i / \rho)_i^{tis})$$

From the above relation, it can be seen that the gamma dose rate depends on the distance R from the source. For this reason, for the evaluation of the gamma dose rate, the distance must also be specified. A default distance of 100 cm is used. In addition, the threshold energy must also be specified. The default value of the threshold energy is 15 keV. Other quantities required for the calculation are the energies E_i and emission probabilities P_i of the radiation, and the mass absorption coefficient $(\mu/\rho)_i^{tis}$ in tissue. The summation index i refers to all the individual gamma and x-ray energies.

The committed effective doses are given by

$$\textit{Committed effective dose for inhalation},\quad E_{inh}(50) = e_{inh}(50) \cdot Activity(Bq)$$
$$\textit{Committed effective dose for ingestion},\quad E_{ing}(50) = e_{ing}(50) \cdot Activity(Bq)$$

Finally, the isotopic power is given by

$$\textit{Isotopic Power } (\alpha) = A \cdot |E_\alpha|$$
$$\textit{Isotopic Power } (\alpha + \beta) = A \cdot |E_\alpha + E_\beta|$$
$$\textit{Isotopic Power } (\alpha + \beta + \gamma) = A \cdot |E_\alpha + E_\beta + E_\gamma|$$

4.1 Nuclide Selector

In the Mass Activity Calculator, the nuclide Co-60 is selected by default. A different nuclide can be selected from the element and mass drop-down menus.

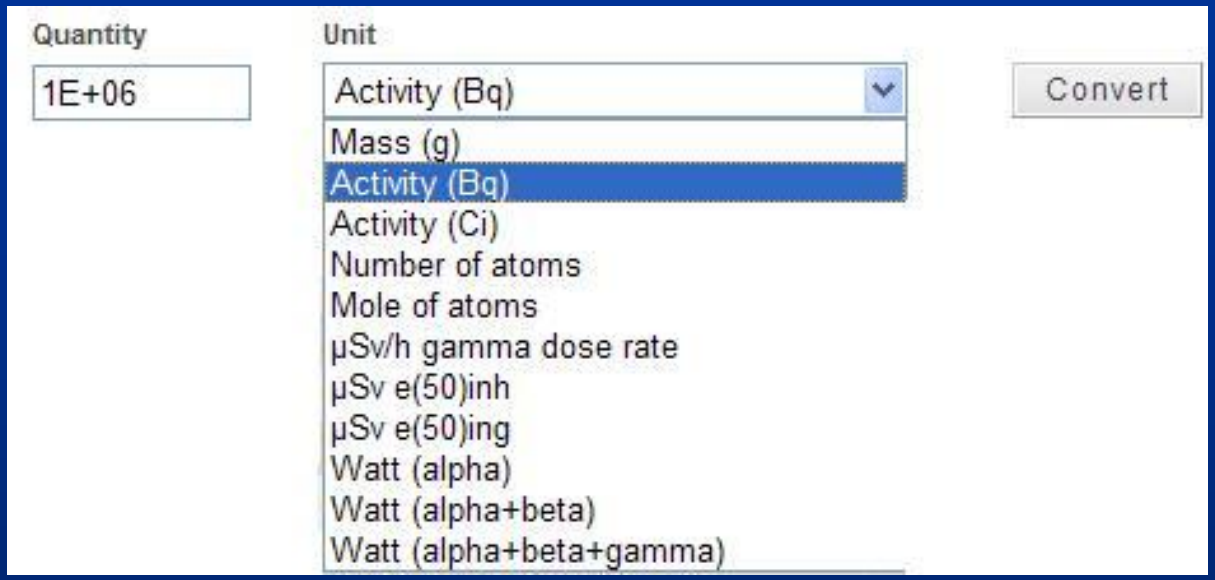
The Nuclide Chart Button shows the location of the selected nuclide on the nuclide chart. To the right of this, the nuclide mixture link can be used to select a nuclide mixture.

The source strength can be specified by using the drop-down menus (see the following section). The default source strength is 1 MBq.

In the Unit/Quantity drop-down menus, the source strength is shown in Becquerel (Bq), Curie (Ci), Number of Atoms, etc. This can then be converted to other units.

4.2 Unit/Quantity Selector

The input unit can be changed in the Unit drop down menu. The default unit is Bq. Had the value Curie been selected, on pressing the Convert button, the corresponding values in grams, Bq, number of atoms etc. are shown in the Convert to/Quantity table.



Once the unit and quantity have been selected in the Unit/Quantity Selector, the source strength in other units is given in the Convert to / Quantity table, by pressing the Convert button. The results are shown for 1 MBq Co-60.

Convert to:	Quantity
Mass (g)	2.388e-8
Activity (Bq)	1.000e+6
Activity (Ci)	2.703e-5
Number of atoms	2.400e+14
Mole of atoms	3.985e-10
Gamma dose rate (µSv/h)	0.3370
Committed Effective Dose Equivalent, e(50)inhalation (µSv)	3.100e+4
Committed Effective Dose Equivalent, e(50)ingestion (µSv)	3.400e+3
Isotopic Power α (Watt)	0
Isotopic Power α+β (Watt)	1.548e-8
Isotopic Power α+β+γ (Watt)	4.161e-7

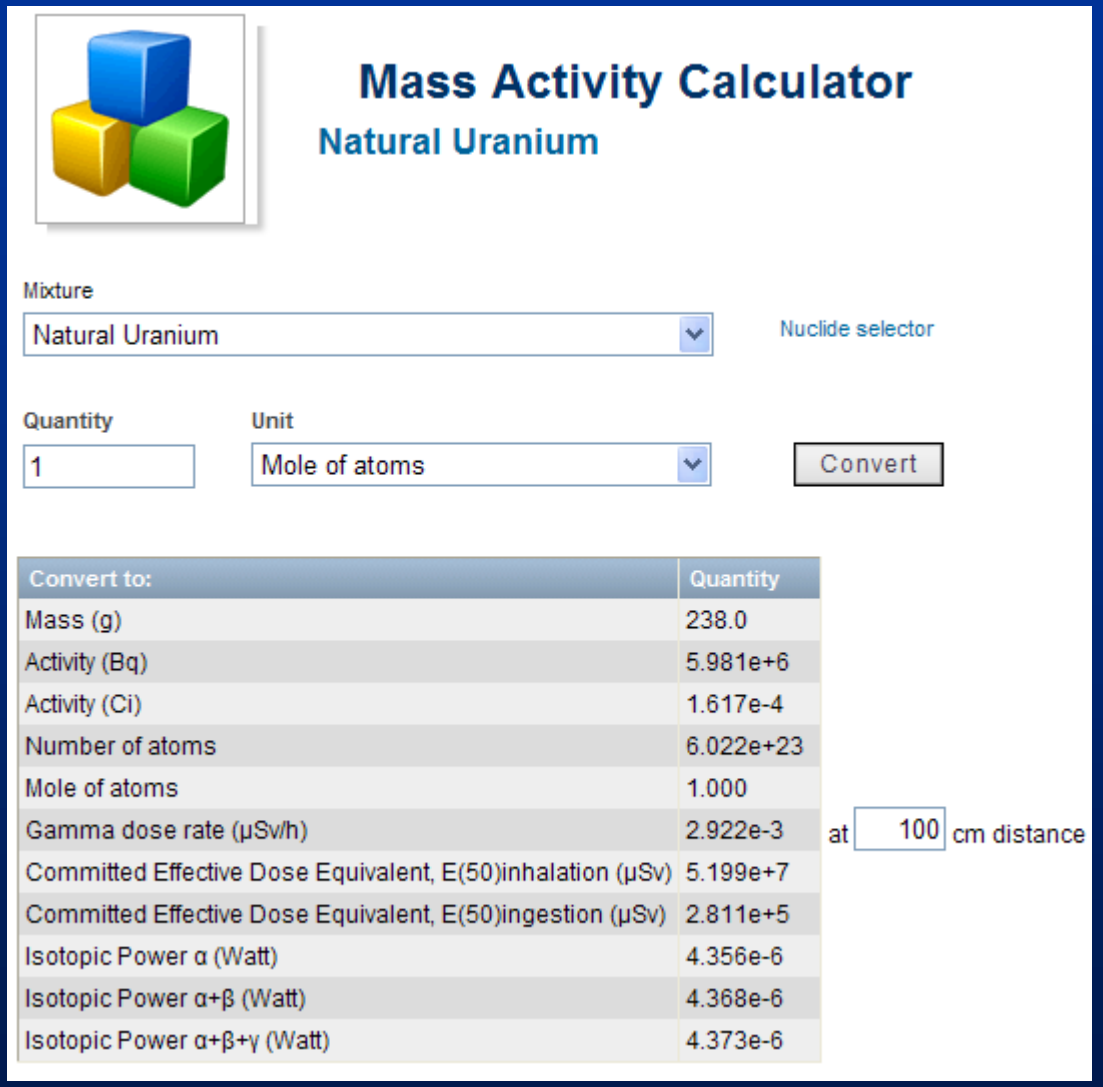
at 100 cm distance (vacuum), Threshold energy (γ & X rays) = 15 keV

5. Nuclide Mixtures

The mass activity calculator can also be used for nuclide mixtures. In the diagram shown, the nuclide mixture “natural uranium” has been selected. This mixture has been previously created in the Nuclide Mixtures module for 1 mole (of atoms) of natural uranium containing

0.9927 mole U-238, 7.114×10^{-3} mole U-235 and 5.310×10^{-5} mole U-234.

As can be seen, even 1 mole of atoms of natural uranium, with a mass of 238 gram and activity of almost 6 MBq (without daughters), has a negligible gamma dose rate and heat emission rate (isotopic power).



Convert to:	Quantity
Mass (g)	238.0
Activity (Bq)	5.981e+6
Activity (Ci)	1.617e-4
Number of atoms	6.022e+23
Mole of atoms	1.000
Gamma dose rate (μSv/h)	2.922e-3
Committed Effective Dose Equivalent, E(50)inhalation (μSv)	5.199e+7
Committed Effective Dose Equivalent, E(50)ingestion (μSv)	2.811e+5
Isotopic Power α (Watt)	4.356e-6
Isotopic Power α+β (Watt)	4.368e-6
Isotopic Power α+β+γ (Watt)	4.373e-6

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6. Exercises

1. **Calculate the specific activities of C-14 and S-35?** (1.7E11 Bq/g (4.5 Ci/g), 1.6E15 Bq/g (4.3E4 Ci/g)).

2. **The activity of Sr-90 is 18,000 transformations per minute. What is the mass of Sr-90?** (Ans. mass = 5.88E-11g).

3. **Six grams of carbon from a piece of wood found in an ancient temple are analyzed and found to have an activity of 10 transformations per minute per gram (from C-14). How many atoms of C-14 are present in the sample and what is their mass?** (2.6E11 atoms, mass = 6.0E-12 g)

4. **The concentration of potassium (K) in humans is about 1.7 g/kg. How much potassium does an average person (weight 80 kg) contain?** (136 g).

   What is the abundance of K-40 in natural potassium? (0.0117%)
   What is the mass and activity of K-40 in this person? (1.59E-2 g, 4.2 kBq).

5. **What is the dose rate from a 100 MBq source of Co-60 at 2m distance**? (8.4 µSv/h)

Thank you!

Summary

In the Radiation Protection module: Introduction to Radiological Quantities and Units, you will become familiar with basic radiological quantities (e.g. activity, specific activity, dose, etc.) and the associated units (e.g. Bq, Ci, Sv, etc.) You will learn how these quantities are derived and the relationships between them.

In a second step you will be introduced to the Mass Activity Calculator in the nuclear science portal Nucleonica (www.nucleonica.com). This is a very user-friendly online tool which is easy to use and allows a quick and accurate conversion of one quantity into a number of others (e.g. to convert an activity into an effective dose if the radioactive material is either ingested or inhaled. Through the Mass Activity Calculator, you will be familiar with other Nucleonica tools such as the calculator, the wiki based Help, and the Glossary (for definitions).

Finally, to underpin the content of this course, a number of problems and exercises will be given.